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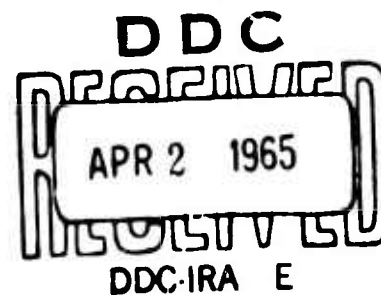
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## LIMITING OF AIRCRAFT SPEED BY AUTOMATIC ENGINE THRUST CONTROL

By H. A. Slingsby  
Beech Aircraft Corporation  
Wichita, Kansas  
Under Contract FA-WA-4639

for



FEDERAL AVIATION AGENCY

WASHINGTON D. C.

DECEMBER 1963

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FEDERAL AVIATION AGENCY

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BY AUTOMATIC ENGINE THRUST CONTROL

By H. A. Slingsby

Prepared for  
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# FEDERAL AVIATION AGENCY

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### LIMITING OF AIRCRAFT SPEED BY AUTOMATIC ENGINE THRUST CONTROL

by H. A. Slingsby

#### SUMMARY

Four systems which vary engine power as airplane speed changes were studied. Three of the systems use a variable pitch propeller with manual control and a governor which maintains constant rpm by controlling throttle position. With the variable pitch propeller set at a fixed pitch, the power required to maintain constant rpm varies as air speed changes, thus the governor automatically changes power as air speed varies. The fourth system uses a conventional constant speed propeller and an air speed sensor system controls the engine throttle. All four systems, when compared to the conventional constant speed propeller - manual throttle system, will automatically limit speed build up in a dive. The systems automatically reduce power when air speed increases, thus much steeper dive angle and rate of descent is automatically allowed for the same forward speed. All four systems can be used for automatic power control in normal flying conditions.

#### INTRODUCTION

This report covers a design study of systems which, through automatic control of the aircraft engine power, will provide some degree of control of the aircraft indicated air speed. There have been many reports of fatal accidents which resulted from high speed build up in a dive when pilots became disoriented when flying under instrument conditions. It is the purpose of this report to investigate methods of automatic control of engine power in proportion to indicated air speed, thus reducing the speed build up which occurs in a dive. An aerodynamically clean airplane has a very rapid acceleration when the nose is pointed down and engine power remains fixed. Such things as lowering flaps and landing gear provide extra drag to allow faster rates of descent with lower forward speed. These methods however, require the pilot to apply them, and they usually would occur as a sudden change after the speed has built up to dangerous limits.

This study covers systems which act to reduce the thrust power of the engine when the air speed is increased above the cruise speed by diving the airplane. The systems are intended to be used for all normal flying control

of the aircraft so they will be in operation to limit speed build up whenever the airplane is dived.

Two general approaches were studied with variations of each. One system uses the performance of a variable pitch propeller, set at a given pitch angle and operating at constant rpm to sense the air speed. The power required to maintain constant rpm with the propeller set at a fixed pitch reduces as air speed is increased. A governor arranged to control the engine throttle will therefore reduce power when air speed is increased to maintain constant engine rpm. The other system uses an air speed sensor and servo motor to control the throttle, and a constant speed propeller to maintain constant engine rpm. In this system increased air speed causes the air speed sensor and servo motor to reduce power thus limiting speed build up in a dive.

#### THE MANUAL-BETA, AUTOMATIC-THRUST CONTROL SYSTEM

The manual-beta, automatic-thrust control system is shown in schematic form in figure 1. This system requires only two pilot controls, an rpm lever, and a beta control lever. These two controls replace the rpm adjustment lever and the throttle lever in the conventional constant speed propeller system.

The propeller in the manual-beta, automatic-thrust system is a variable pitch type with a manual pitch control. The propeller may use either a hydraulic actuator or an electrical mechanical actuator to change the pitch angle. With either type of actuator the pitch must lock in the position set by the pilot. A hydraulically operated pitch actuator which uses an oil transfer bearing, subject to possible leakage, may be used if provisions are made to maintain a fixed pitch while leakage is occurring. This may be done through use of a solenoid shut off valve located in the propeller. Slip rings are then required to furnish power to the valve. Another method is a continuous flow system using a position follow up spool valve. The valve spool would be positioned by the propeller pitch changing mechanism through a bearing at the propeller hub. The valve body would be positioned by the beta control lever. When the valve is at neutral position, propeller pitch would be fixed; any pitch change causes oil flow to maintain the desired propeller pitch angle. Moving the valve body causes oil to flow to change pitch to a new angle.

#### ENGINE OVERLOAD PREVENTION

##### WITH THE MANUAL-BETA, AUTOMATIC-THRUST CONTROL SYSTEM

The automatic-thrust control system increases power when air speed decreases; thus if the pilot pulls up into a climb, engine power can be increased above the recommended limit. Switch 7 of figure 1 is an absolute

pressure switch connected to engine manifold pressure. When manifold pressure increases enough to close switch 7, the beta angle is decreased. When beta angle is decreased, less power is required to maintain the engine rpm and the governor closes the throttle which reduces manifold pressure. The recommended manifold pressure limit for an engine increases with increased rpm, therefore the system of figure 1 is arranged such that changing the rpm lever resets the pressure closing point of switch 7. Figure 3 shows a typical manifold pressure limit VS RPM for an aircraft engine. The mechanism should be designed to follow the recommended values of the engine in use. When the pressure limit of switch 7 is reached, propeller pitch will reduce until the manifold pressure has reduced by the amount of the switch differential. A practical differential pressure between the switch closing point and the switch opening point is 1 inch of mercury. On two typical 6 cylinder aircraft engines rated at 185 and 260 horsepower, a reduction of one inch of mercury manifold pressure results in a decrease of approximately 10 horsepower. The pilot can obtain more power for a climb by increasing the rpm.

#### TAKE-OFF ANALYSIS WITH THE MANUAL-BETA, AUTOMATIC-THRUST CONTROL SYSTEM

The system automatically provides full power for take off. Referring to figure 1, when the rpm lever is moved to the take off position, switch 3 is closed. The full rpm setting requires the governor to open the throttle to full open under static conditions. When the throttle is not full open switch 5 is closed. Switch 5 acts to increase propeller pitch which increases power required, which in turn causes the governor to open the throttle. When the throttle reaches the full open stop, the throttle arm is allowed to over travel and open switch 5 which stops increasing propeller pitch. If rpm is below the governor setting the governor moves the throttle farther into the second over travel position which closes switch 4. When switch 4 closes propeller pitch is reduced to reduce power required. The result of the action of switches 4 and 5 is to position beta at the correct angle for full throttle power. Switch 3 assures that this will occur at high rpm as required for full power operation and take off. As airplane speed increases, power required to maintain rpm is reduced and switch 5 closes to increase beta to maintain full power as long as the rpm lever is in the take off position.

The addition of switches 3, 4, and 5 is a relatively inexpensive means of automatically providing full power during take-off. The addition of 3 switches and the over travel linkage on the throttle arm reduces reliability. The design of a system including this feature should compare the reduction in reliability with the gain in performance. Omitting these switches will increase the take off run a small amount, since engine power will reduce as air speed increases. The pilot could manually reset beta to regain this power.

## LANDING ANALYSIS

### WITH THE MANUAL-BETA, AUTOMATIC-THRUST CONTROL

The system of figure 1 can be used to land the airplane. There are two methods which may be used:

1. With the propeller low pitch stop set to limit static rpm at full throttle, power may be reduced by reducing the rpm setting of the governor.
2. If the beta can be reduced to a zero thrust value, power can be reduced to zero at high rpm with the beta lever.

In method 1 the system is as shown in figure 1. The governor must be capable of controlling engine speed over the range from idle to take off rpm. Method 1 allows the propeller low pitch stop to be set as required by CAM 3 paragraph 3.421. In reducing power for landing by use of the rpm lever, the pilot can get full power for aborted landing by moving the rpm lever to take off position. This will result in automatic adjustment of the beta angle for full throttle power at take-off rpm.

In Method 2 the propeller must be arranged to allow reducing beta angle to approximately a zero thrust condition at high rpm and landing approach speeds. The rpm lever would be set at a value to give high rpm but not to close the full power switch. The beta lever would then be used to reduce thrust by reducing propeller pitch. Full power would be obtained for an aborted landing by moving the rpm lever to full power position which automatically resets the beta angle for full power condition.

The pilot could also attempt to reset to full power for aborted landing by increasing the beta angle. In this case the manifold pressure switch must be arranged to prevent overloading the engine by overriding the beta control lever when the manifold pressure reaches the limiting value.

The use of a propeller pitch angle low enough to provide nearly zero thrust at landing approach speeds does not allow the propeller low pitch stop to be set as required by Civil Aeronautics Manual 3, paragraph 3.421. Full throttle operation would result in overspeeding the engine since there is no load to absorb the power. A second governor or topping governor is required to protect against failure of the operating governor. This second, or topping, governor could be set at a value slightly higher than the operating governor which controls the throttle. The topping governor can act to control either the throttle or the beta angle. If it is arranged to control the beta angle a failure of the operating governor would result in full power application with beta angle increased to prevent engine overspeeding. The application of this arrangement to an airplane will require detailed operation and failure analysis to assure equivalent safety for all modes of operation in a particular case.

## PROPELLER DRAG

### WITH THE MANUAL-BETA, AUTOMATIC-THRUST SYSTEM

The manual-beta, automatic-thrust system shown by figure 1 may be used to obtain high drag automatically if desired for limiting speed in a quick descent. To provide maximum practical drag capability, switch 6 of figure 1 would be replaced by a topping governor switch arranged to override the beta control lever and increase beta angle when the topping governor set value is reached. The topping governor should be arranged such that its set value is a small amount (50 to 100 rpm) higher than the operating governor setting. In operation the pilot would reduce the propeller pitch with the beta lever until the operating governor closes the throttle and rpm increases a small amount. This provides a closed throttle high rpm condition which produces high drag.

## REVERSE PITCH OPERATION

### WITH THE MANUAL-BETA, AUTOMATIC-THRUST SYSTEM

If it is desired that the system provide reverse propeller pitch operation it is necessary to arrange the system to prevent its use in flight. The system described by figure 1 will accomplish this for normal cruise flight speeds if switch 6 is replaced by a topping governor as described in the paragraph on propeller drag. This topping governor will prevent using reverse pitch as long as forward velocity is high enough to cause the propeller to windmill at the topping governor rpm setting. At slower speeds, however, a mechanical low pitch stop is required to prevent reverse thrust operation. This low pitch stop could be automatically removed by a switch which is actuated when weight is applied to the landing gear.

After touchdown, and the removal of the low pitch stop by the landing gear switch, the beta lever can be used to apply reverse propeller pitch as required to assist in stopping. As the reverse propeller pitch is applied, the governor will automatically open the throttle to maintain constant engine rpm and the amount of reverse thrust is controlled by the position of the beta control lever.

Engine rpm is controlled by the governor which positions the throttle. Power output is controlled by the beta control lever, except when the rpm lever is placed in full power position which automatically moves the beta control to the position required for full forward power. If a throttle control governor malfunction occurs which results in an open throttle condition, engine overspeeding is prevented by the topping governor which

adjusts the beta angle to absorb the power. A specific application of this system will require a detailed failure analysis to show safety equivalent to systems now in use.

## MAGNETO CHECKING

### WITH MANUAL-BETA, AUTOMATIC-THRUST CONTROL

The procedure required for checking the magneto is different than that for an airplane with a manual throttle. A faulty magneto will cause a change in manifold pressure while the governor maintains constant rpm. Manifold pressure change limits can be established for the system such that an acceptable magneto check can be performed in pre-flight check out.

## ELEVATOR - THROTTLE COUPLING

### WITH THE MANUAL-BETA, AUTOMATIC-THRUST CONTROL

Many airplanes have a pitching moment change with power or thrust change. A system which automatically reduces power as air speed increases may tend to increase the dive angle as power is reduced, thus the speed build up may be increased rather than decreased. A system of air speed limiting by automatic power control would then be unstable. The automatic power control system moves the throttle closed as speed increases; if this throttle movement is connected to the elevator, a nose up pitching moment can be introduced as speed increases to pull the airplane out of a dive. Figure 1 shows the throttle connected to the elevator control cables through a down spring. As the throttle moves toward closed position the spring tension is reduced thus producing an up-elevator and nose up pitching moment.

The normal trim of an airplane is speed sensitive. An increase in speed produces a nose up pitching moment and vice versa. Any system which tends to make the airplane fly at constant air speed by power reduction will tend to reduce the normal trim correction moments.

In addition to counteracting the loss in trim due to limiting the speed change by control of power, and the pitching moment due to changing power, the throttle - elevator coupling may provide more speed limiting by decreasing the dive angle before speed can build up to a dangerously high value. Application of the throttle - elevator couple must be designed and tested for each airplane model. It may be helpful on some and detrimental on other airplanes.

## PERFORMANCE

### WITH THE MANUAL-BETA, AUTOMATIC-THRUST CONTROL SYSTEM

The performance of the manual-beta, automatic-power control system is determined through use of figure 4 and 5. Figure 4 is a family of curves showing the variation of the beta angle with air speed. These curves were calculated using the "Hamilton Standard Method of Propeller Performance Calculation." The performance is based upon an airplane with a 260 horsepower engine and a 2 blade 82 inch diameter adjustable pitch propeller. The performance is determined as follows. Select a cruise power setting and air speed; for example, 182 mph on the 2450 rpm 195 hp curve which indicates a beta angle of  $24.3^\circ$ . The air speed increase required for the governor to close the throttle is determined by moving horizontally, to the right, to the intersection of the zero thrust 2450 rpm curve. This shows that the zero thrust air speed for a beta angle of  $24.3^\circ$  is 237 mph. A speed increase of 55 mph is required for the system to reduce power to zero. Rechecking at various power settings will show that the speed increase required increases when the cruise power setting is increased.

Figure 5 is a family of curves showing the change in thrust power required for constant rate of descent at various air speeds. This set of curves was calculated for an airplane with a gross weight of 3125 pounds. The performance of the manual-beta, automatic-thrust system can be compared with the conventional constant speed propeller equipped airplane and the direct air speed sensing system by use of figure 5.

A principal performance factor desired from the systems under study is the ability of a system to limit forward speed in a dive. Figure 5 can be used to determine the rate of descent of all three systems at any air speed. For example, the constant speed propeller system performance is shown by a horizontal line, that is, a constant thrust power line. The manual-beta, automatic-power system performance is shown by a line connecting the cruise speed and the zero thrust power speed. The direct air speed sensing system performance is shown by a line connecting the cruise speed with the zero thrust power speed. This comparison has been made in Table 1, which shows the forward speed for each system at 250 ft per min increments of rate of descent.

### THE NEGATIVE DROOP MANUAL-BETA,

### AUTOMATIC THRUST CONTROL SYSTEM

With the manual-beta, automatic-thrust control system, the forward speed required to reduce power to zero will be reduced if the governor system is arranged to reduce rpm as power is reduced. For example, referring to figure 4, if we select a cruise speed of 182 mph on the 195 hp 2450 rpm curve and move to the right at the same propeller blade angle ( $24.3^\circ$ ) to the intersection of the 2100 rpm zero thrust curve, we find a forward speed

of 205 mph. If we had started at the same cruise condition and engine rpm was reduced to 1850 rpm at zero thrust, the zero thrust speed would be approximately 182 mph, or zero speed increase. Proper selection of the amount of reduction of engine rpm with decrease in power will enable this system provide the maximum possible speed limiting within the capability of the engine and propeller.

A governing system which reduces speed as power is reduced is said to have negative droop. Normally speed control governors use positive droop to provide stability and a negative droop system is inherently unstable. A governor requires a speed error signal to cause it to make a correction in throttle position; thus an overspeed condition causes the throttle to close. With droop control the closing of the throttle increases the governor rpm setting; thus reducing the error signal which stabilizes the system. With negative droop an increase in rpm would result in closing the throttle; closing the throttle decreases the rpm setting, which increases the error signal. An increase in error signal causes more correction and the governor would cycle the throttle from full open to closed positions.

There are two methods which may be used to provide a stable negative droop system. The governor can be arranged such that throttle position determines the rpm setting. The connecting linkage would include time delay such that rpm reset by throttle position change would occur slowly, compared to throttle movement. A system of this type introduces some operational problems. The time delay for the throttle to reset rpm is limited to a speed which is equal to or faster than the airplane forward speed acceleration. This amount of time delay may be as much as 10 seconds. When the pilot adjusts rpm, the delayed throttle rpm reset would cause rpm to change after it has been set. Small changes in air speed during cruise operation will cause rpm to vary.

The rpm reset mechanism could use manifold pressure instead of throttle position as the signal to reset the governor. In this case, rpm would be increased as manifold pressure increases. Governors have been produced with this negative droop feature for speed control of industrial engines.

Another method to introduce a negative droop is to provide a speed reset in one or more steps. For example, when power is reduced to 40 percent, as indicated either by throttle position or manifold pressure, the governor setting can be reduced by 200 or 300 rpm. This system provides stable operation, but will not permit operation below 40 percent power. The system also provides a step in power which may effect the stability of the airplane for recovery from a dive under hands off conditions.

Either of these two methods of introducing negative droop can be designed to make a system reduce power at a faster rate than the system which operates at constant rpm. It will be necessary to design, build and test a

system to determine the effect on airplane stability and the pilot acceptance to the system.

## THE LOCKPITCH SYSTEM OF BETA AND THRUST CONTROL

Figure 6 is a schematic diagram of a system which provides for the governor to control either the propeller pitch or the throttle. Two control levers are provided, an rpm control, and a throttle control. If the pilot moves either lever the governor is switched to control the propeller while the lever is being moved. When the rpm lever is moved to take off position, the system operates with the governor controlling propeller pitch and the manual throttle controls the engine power. When the rpm lever is moved away from the take off position, a switch is actuated to change the governor to throttle control, and propeller pitch is locked. A new propeller pitch setting can be obtained by moving either the rpm lever or the throttle. While either lever is being moved the governor will control propeller pitch, and after the lever is released the governor is changed back to throttle control with locked propeller pitch.

When the throttle reaches either full closed or full open position a limit switch is actuated to convert the governor to propeller pitch control to prevent over speeding or additional loading.

The system requires use of a propeller which will maintain a fixed pitch when oil flow to the propeller is stopped. The conventional hydraulically actuated constant speed propeller which receives its oil through a transfer bearing cannot be used because the transfer bearing normally used may leak allowing the beta angle to change. A hydraulically actuated propeller can be used if a follow up valve is used to control the propeller pitch. The governor would then position the follow up valve, which in turn would cause the correct oil flow to the pitch actuator to maintain the desired pitch angle.

The lockpitch system requires that the governor be capable of stable operation when controlling either the propeller beta angle or the throttle position. This may be possible, however the dynamic response is not the same in both cases, and development problems are very likely to arise in this respect.

The advantage of the system is that it retains the constant speed propeller system for take off under full power as well as providing speed build up limitation in flight by use of propeller locked pitch and a governor on the throttle. The performance of the system in flight is the same as the manual-beta, automatic-thrust system of figure 1.

## THE DIRECT AIR SPEED SENSING SYSTEM

The direct air speed sensing system uses a conventional constant speed propeller with a governor controlling beta angle to maintain constant engine rpm. An air speed sensor and servo motor is used to control the throttle.

Ideally the air speed sensor should position the throttle to maintain constant indicated air speed. In an actual system however, it does not appear possible to design a control which will provide constant air speed. To provide performance data for this system, the preliminary design of an electrical air speed sensing system has been made. The system selected is shown in schematic form in figure 2. A double acting pressure switch is used to sense air speed and a two direction dc motor is used to position the throttle. The pressure switch is arranged so that both of its switches are open at the set air speed. The pressure diaphragm is connected to the airplane pitot static system. An increase in air speed closes the decrease power switch and a small decrease in air speed opens the decrease power switch. A further decrease in air speed closes the increase power switch, and a small increase in speed opens the increase power switch.

The preliminary design used 180 mph as the design point. The decrease power switch closes at 182 mph and opens, after closing, at 181.2 mph IAS. The increase power switch closes at 177.5 mph IAS, and opens after closing, at 178 mph IAS.

When the pressure switch is readjusted for control at 80 mph IAS, operation is as follows. The decrease power switch closes at 83.4 mph IAS, and opens after closing, at 82.7 mph IAS. The increase power switch closes at 76.9 mph IAS, and opens after closing, at 77.1 mph IAS. The dead band, or air speed range in which no throttle correction is made, is larger at slow speed settings because the velocity pressure varies as the square of the velocity.

The electric motor throttle actuator must move the throttle fast enough to correct for the highest air speed acceleration of the airplane. A small throttle movement however will not produce rapid acceleration of the airplane; thus with the system described, the throttle will move full travel each time the air speed pressure switches close. To prevent full throttle movement for small speed changes, the throttle is connected to change the pressure switch speed setting as it moves.

In the preliminary design, full throttle travel resets the air speed sensor 5 mph at 180 mph and 12.6 mph at 80 mph. The throttle position speed reset causes the system to make small power corrections for small speed error and large power correction for a large speed error. When the decrease power switch is closed the throttle moves toward closed position which increases the speed setting of the pressure switch. Increasing the speed setting opens the decrease power switch after small throttle travel.

The addition of the throttle-coupled speed-reset, to prevent large power adjustments for small speed error, increases the dead band of the system. With the throttle coupled speed reset the dead band is increased to 9 mph IAS at 180 mph and to 19.1 mph at the 80 mph IAS setting. This wide dead band speed in which no power correction is made makes it doubtful if the performance of the system will be acceptable. The dead band may be decreased by smaller switch actuation travel, or by use of a speed spring with smaller load rate. The unit used in preliminary design used the smallest practical switch travel; movement of the diaphragm to actuate switches was .019 inches. A smaller spring rate would result in a much longer spring which tends to become unstable and requires longer travel for adjustment of the speed.

The pressure switch and electric motor throttle actuator arrangement was selected for evaluation because it is simple and inexpensive. Calculated performance however, indicates it will not be satisfactory as a power control device in an airplane. Other more sophisticated and possibly higher cost approaches can very probably be developed with adequate performance for this application. An air speed sensor capable of moving the throttle proportional to air speed, and providing full throttle travel for about 5 to 10 mph speed change over the speed range of 60 to 180 mph would make performance of the direct air speed sensing system better than that for the other systems described in this report.

#### COMPARISON OF SYSTEMS

Each of the systems, the manual-beta automatic-thrust system, the negative droop manual-beta automatic-thrust system, the lock pitch system, and the direct air speed control system, can use the throttle - elevator coupling to limit air speed build up by limiting the dive angle. A comparison of systems with the throttle - elevator coupling is difficult since the amount of coupling applied to each system to change the dive attitude will effect performance. A comparison can be made if the throttle - elevator coupling is not included.

Figure 5 is a family of curves showing the thrust horsepower required for various constant rates of descent or climb vs true air speed. The amount of speed limiting can be determined by the rate of descent required to cause the airplane to have the same forward speed with the different systems. The evaluation in this manner actually is based upon replacing engine power removed by an increased dive angle.

Using the performance of figure 5, the constant speed propeller - manual throttle system is represented by a horizontal line, or constant power line. The other systems are represented by a line connecting the cruise condition power and speed with the zero thrust air speed. A comparison was made of the three systems with the constant speed propeller manual throttle system and is presented in Table 1.

A comparison of the four systems at 1000 ft per minute rate of descent, after adjustment for cruising at 160 mph and 114 hp, is as follows:

1. The constant speed propeller manual throttle system - zero power reduction.
2. The manual-beta, automatic-thrust control system - 50 hp or 43.7 percent power reduction.
3. The manual-beta, automatic-thrust control system with negative droop speed control - 70 hp or 61.4 percent power reduction.
4. The direct air speed control system - 77 hp or 67.5 percent power reduction.

The direct air speed system was assumed to be capable of adjusting power to zero with a 20 mph speed increase. The amount of speed increase for this system will be dependent upon the sensitivity which can be designed into the air speed sensor.

#### FLIGHT TESTING OF THE MANUAL-BETA,

#### AUTOMATIC-THRUST CONTROL SYSTEM

A single-engine low-wing airplane was modified to include a manual-beta, automatic-thrust control system, and flight tests were performed. This airplane was selected for modification and flight test because it was already equipped with an adjustable pitch propeller and manual pitch control. A three view drawing of the flight test airplane is shown in figure 16. The modification to the airplane is shown in schematic form in figure 7. The modification consisted of the addition of a hydraulic governor and adapter, a hydraulic throttle actuator and pilots controls. The manual controls consisted of an rpm adjustment control, and a by-pass valve control. The by-pass valve was used to enable the pilot to use either a manual or automatic throttle as desired. The needle valve shown in the schematic diagram was used to adjust the governor response rate to enable stable operation.

The system performed as desired for the testing program. The external oil lines however, resulted in a very stiff throttle until the engine was thoroughly warmed up. Any use of this system for a production airplane should include an arrangement which eliminates the long external oil lines. The dive recovery tests with aft center of gravity loading were performed on a much colder day, ambient temperature 7°F, and governor response was too slow to provide a true indication of the system performance.

Figures 8 through 12 are photographs of the test airplane and installation of the system components.

### CONTROLLED DIVE PERFORMANCE

The performance of the propeller used in the flight tests was calculated using the Hamilton Standard Method of Performance Calculation, and is shown in figure 13.

To determine the amount of engine power reduction with speed increase the airplane was flown to 6000 ft altitude and trimmed for 130 mph IAS, 1875 engine rpm, and 17.2 inches Hg manifold pressure. A controlled dive was then started and data recorded for each 10 mph IAS increase in air speed up to a speed where the governor closed the throttle. The test was then repeated starting at 6000 feet altitude 148 mph IAS 2040 engine rpm, 20.5 inches Hg manifold pressure.

The results of these two tests are shown in figure 14. Figure 14 also shows the change in power with speed as determined from the calculated performance shown in figure 13. The calculated or predicted performance compares very well with the performance found by test.

### THE NEGATIVE DROOP STEP CONTROL

#### MANUAL-BETA, AUTOMATIC-THRUST CONTROL SYSTEM

In the study it was determined that the speed increase required for the governor to reduce power to zero would be decreased if the rpm were reduced as power is reduced. This type control was not included in the test airplane, therefore this test consisted of simulation of the one step method of negative droop control. The airplane was flown to 6000 ft altitude and trimmed for 120 mph IAS, 1850 rpm, and 17.2 in. Hg manifold pressure. A dive was started to increase air speed. When manifold pressure reduced to 14 inches Hg the governor setting was quickly reduced from 1850 to 1600 rpm. Fourteen inches Hg manifold pressure occurred at a speed of 134 mph IAS and the throttle was closed at 145 mph IAS. This test confirms the calculated performance shown by figure 13. Referring to figure 13, a horizontal line through 120 mph on the 1850 rpm 82.5 Hp curve shows zero thrust at 145 mph for 1600 rpm and 168 mph for 1850 rpm.

### DIVE RECOVERY

The ability of the airplane to recover from a dive is an important consideration for evaluation of the system. Addition of the system may tend to stabilize the airplane or it may reduce stability.

In these tests the airplane was flown to 7500 ft altitude, trimmed for stable flight at 140 mph IAS 2050 rpm and 19 inches Hg manifold pressure. The airplane was then pulled up into a climb until a steady 100 mph IAS was obtained and controls were released. These tests were repeated with forward and aft center of gravity loading and with the three power control systems available in the airplane. The test airplane could be flown with the manual-beta, automatic-thrust system, with the fixed propeller pitch - fixed throttle system, and with a constant speed propeller manual throttle system. The data for these tests is shown in Tables 2 through 7.

When the airplane was flown with a forward center of gravity loading, the manual-beta, automatic-thrust control system provided some stabilizing effect in dive recovery. The dive recovery with this system was made in about 3-1/2 cycles of the phugoid. Dive recovery with the fixed pitch - fixed throttle system required about 5-1/2 cycles of the phugoid.

When the airplane loading was moved to aft center of gravity, the governor system provided slow throttle response due to cold ambient temperature on the external oil lines. This is shown by the data of Table 5 where engine speed varies from 1700 to 2200 rpm. If the governor response had been as required the engine speed would have remained constant. Comparison of the rpm of Table 5 and Table 7 indicates some governor control was obtained since speed variation was larger with the fixed throttle fixed propeller system.

With the aft center of gravity loading the dive recovery showed higher maximum and lower minimum air speed in the phugoid. The dive recovery was discontinued when it was evident that the phugoid was being damped out.

#### TIME TO ACCELERATE AT FIXED DIVE ANGLE

An attempt was made to determine the time for the airplane to accelerate when trimmed for cruise conditions and dived at a fixed angle. In these tests the airplane was trimmed for cruise flight at 8000 ft altitude and 130 mph IAS. A dive was then made to a steady state 200 mph and the windshield was marked to sight on the horizon. Using this method of controlling the airplane at a fixed angle, the time was measured for the airplane to reach an increased speed from the cruise condition.

With the airplane operating on the constant speed propeller - fixed throttle system the time to accelerate from 130 mph to 170 mph was 22 seconds or 1.82 mph per second.

With the manual-beta, automatic-thrust system the time to accelerate from 130 mph to 160 mph was 33 seconds or an acceleration of .91 mph per second. Using this system we had intended to measure time to increased

speed of 170 mph. The system, however, limited speed build up such that about 165 mph would have been the maximum speed obtained at the fixed dive angle.

These tests indicate that the acceleration of the airplane with manual-beta, automatic-thrust control is about 50 percent of that for the constant speed propeller manual throttle system, when the dive angle is the same for both systems.

#### DIVE ANGLE FOR FIXED SPEED INCREASE

In these tests the airplane was flown at approximately 8000 ft altitude, trimmed to cruise conditions and then dived at constant dive speed. The instrument panel was photographed at approximately 5 second intervals to provide the data shown in Table 8.

Two comparison flights were made for each system. The airplane was flown to approximately 8000 ft and trimmed for 120 mph cruise conditions, then dived to a constant 160 mph speed. In the second test the airplane was flown to approximately 8000 feet altitude and trimmed for 150 mph cruise condition, then dived to 180 mph steady state conditions.

The data from these flights was used to determine the rate of descent by averaging the loss in altitude for each increment of time. The dive angle for each system was determined. The results were as follows:

1. With the manual-beta, automatic-thrust system trimmed for 120 mph and dived to 160 mph, the dive angle was 7.85°.
2. With the constant speed propeller - manual throttle system trimmed for 120 mph and dived to 160 mph, the dive angle was 3.24°.
3. With the manual-beta, automatic-thrust system trimmed for 150 mph and dived to 180 mph, the dive angle was 4.9°.
4. With the constant speed propeller manual throttle system trimmed for 150 mph and dived at 180 mph, the dive angle was 2.94°.

These tests show that the dive angle required to produce the same speed increase is almost twice as large for the manual-beta, automatic-thrust system as it is for the constant speed propeller manual throttle system.

## STICK FORCE MEASUREMENTS

In this test the airplane was flown to 8000 ft altitude and trimmed for 140 mph IAS. The stick force required to hold the airplane in 10 mph dive and climb increments was measured with the manual-beta, automatic-thrust control system and with the constant speed propeller system. The results of this test was shown in figure 15.

The change in stick force due to the manual beta system were very small. In climb attitude the forces were higher than for the constant speed propeller system, and in dive attitude the forces were less.

The climb test was limited to a climb attitude that did not result in reduced rpm because at this point the manual-beta, automatic-thrust system is at full power condition. If the system had included the manifold pressure switch shown in figure 1 the beta angle would have started to reduce at this point to limit power; and if the climb were continued to slower air speed the pilot would be required to increase the rpm setting.

## CONCLUSION

The systems studied will provide a reduction in the rate of speed build-up and an increase in the rate of descent in a dive at given air-speed when compared to a conventional system using a constant speed propeller at fixed power. A flight test on one airplane indicated that the system may be applied without detrimental effects on the dynamic longitudinal stability of the airplane. Flight tests on other airplanes would be required to assure that static longitudinal stability is not affected. The manual-beta, automatic-thrust control system can be used as the power control system for normal flying operation including landing, take-off, cruise, taxi, and engine preflight check.

The application of the throttle-elevator coupling to provide a nose-up pitching moment when power is reduced should improve the speed limiting of the power control systems. Application of this device will require detailed study and development testing for each airplane to which it may be applied. Airplanes which have little or no change in the pitching moment with power change may not require the elevator-throttle coupling arrangement. The airplane used for flight testing performed quite well without this feature.

The manual-beta, automatic-thrust control system does not increase the number of controls for the pilot. The systems are somewhat more complicated than the constant speed propeller system, thus will cost more. Some loss in reliability may result due to the larger number of components required in these systems.

The direct airspeed sensing system can be shown to provide more reduction in the rate of speed build-up in a dive if the sensitivity of the device is improved over that of the pressure-switch, motor-actuator system evaluated.

Wide variations in sensed airspeed can occur during flight in turbulence. Since airspeed stabilization through modulation of power is the basic goal being sought in the systems studied, the variation in sensed airspeed in turbulence could cause power changes of unnecessary and undesirable magnitude unless the response rate and natural frequency of any particular system were carefully arranged to avoid these large amplitude, short period power fluctuations.

It is believed that such tailoring of response rate and natural frequency can be accomplished easily.

The systems studied attempt to keep indicated airspeed constant by increasing or decreasing power within power plant and propeller capabilities as airspeed tends to vary from its trimmed value in response to either

atmospheric disturbance or the pilot's control inputs. Sensitivity to pressure altitude changes was not one of the design-goals in any of the systems studied. Lacking pressure altitude sense, an airplane with one of these systems operative would not necessarily tend to maintain pressure altitude within very close limits. Since maintenance of altitude within close limits is important during instrument flight, there is no assurance that installation of one of these systems would make the aircraft in which it was installed either more or less difficult for the trained instrument pilot to fly in instrument flight conditions.

#### ACKNOWLEDGMENT

The author acknowledges the assistance of the Woodward Governor Company of Rockford, Illinois who furnished the governor for the flight test airplane and the schematic and system description for the lockpitch propeller control system presented in figure 6. The author thanks Mr. T. W. Sanford of the Federal Aviation Agency Aircraft Development Service for his guidance in the performance of this design study. The author thanks Mr. J. T. Calhoun and Mr. O. W. Scott and others of Beech Aircraft Corporation for their assistance in the performance of this design study.

## APPENDIX

### Symbols and Abbreviations

Beta ( $\theta$ )	- Propeller pitch angle measured at the $3/4$ radius, degrees
RPM	- Revolutions per minute
MPH	- Miles per hour
IAS	- Indicated air speed
MP	- Manifold pressure, inches of mercury
Hg	- Mercury

### References

The Hamilton Standard Method of propeller performance calculation by the Hamilton Standard Propellers division of United Aircraft Corporation, East Hartford, Conn.

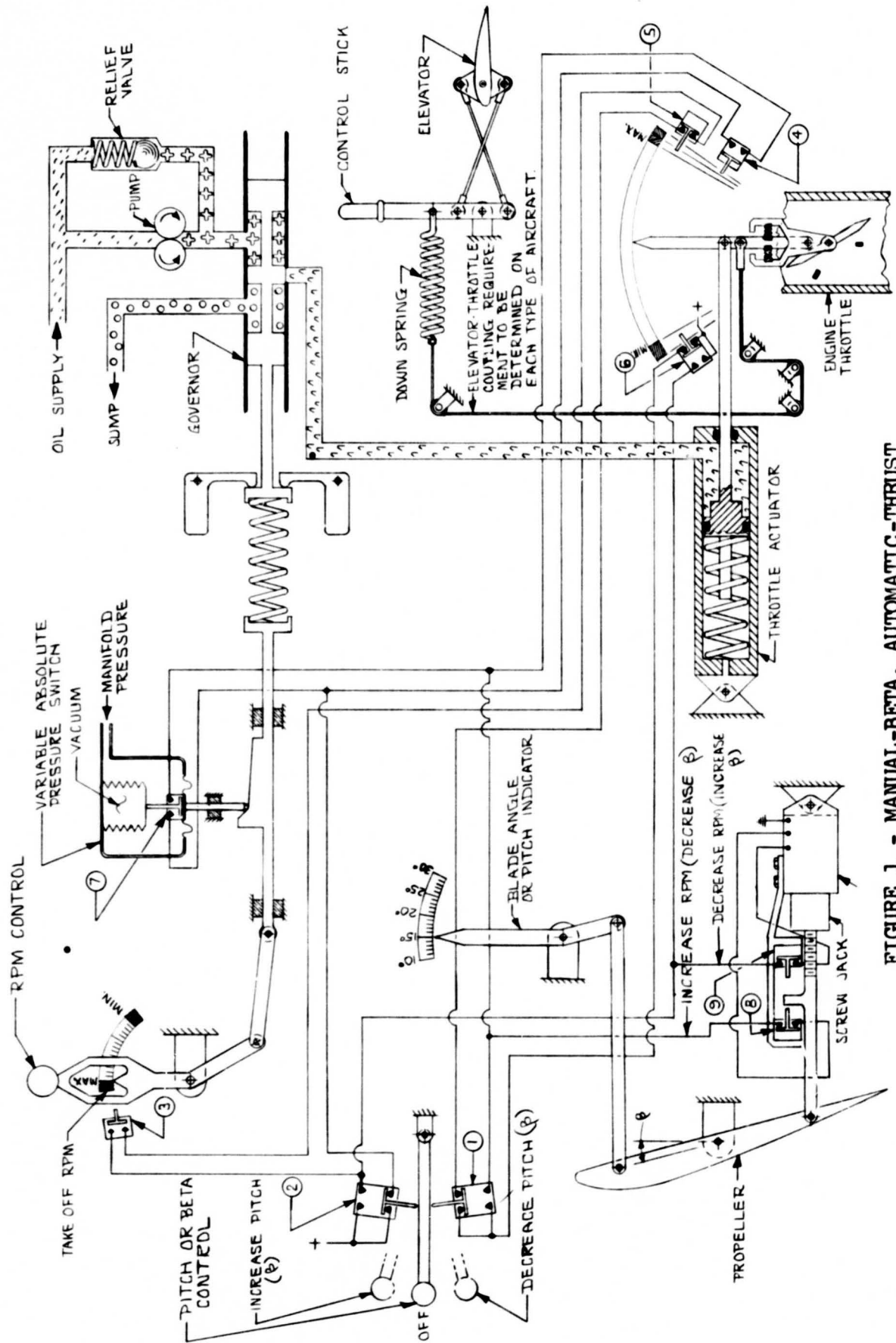


FIGURE 1 - MANUAL-BETA, AUTOMATIC-THRUST  
CONTROL SYSTEM SCHEMATIC DIAGRAM

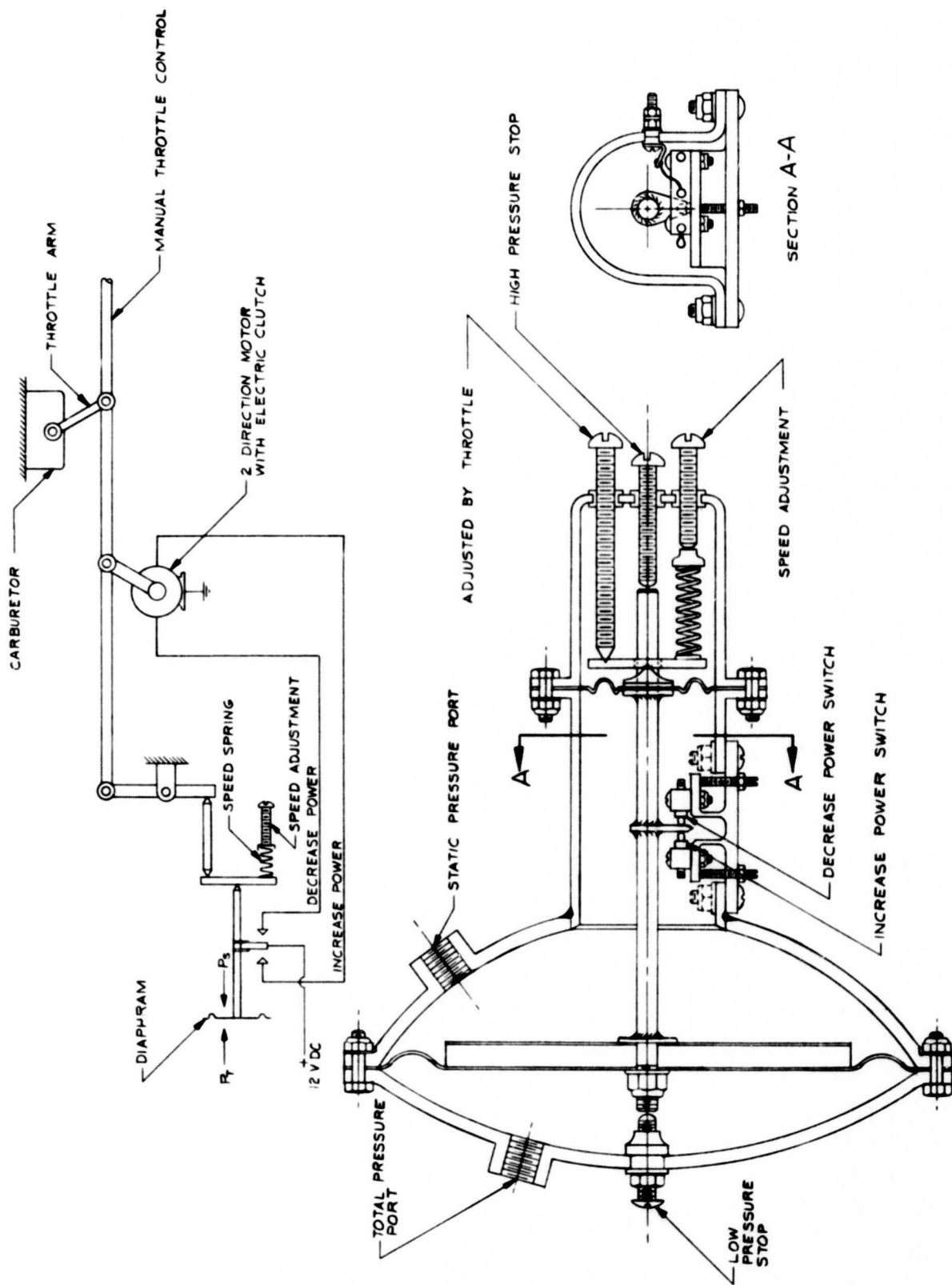


FIGURE 2 - AIRSPEED SENSOR & CONTROL SCHEMATIC

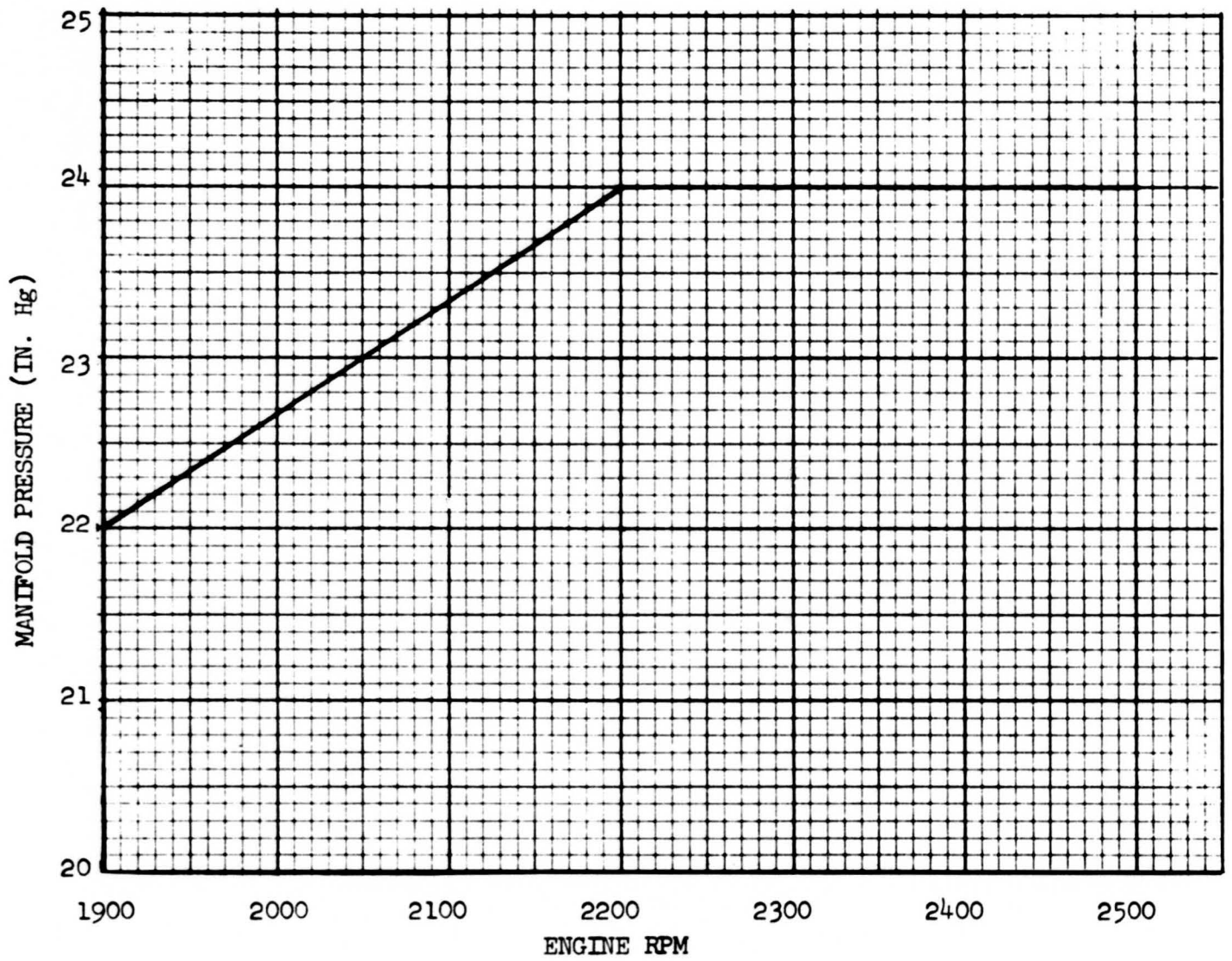


FIGURE 3 - TYPICAL MANIFOLD PRESSURE LIMIT FOR AN AIRCRAFT ENGINE.

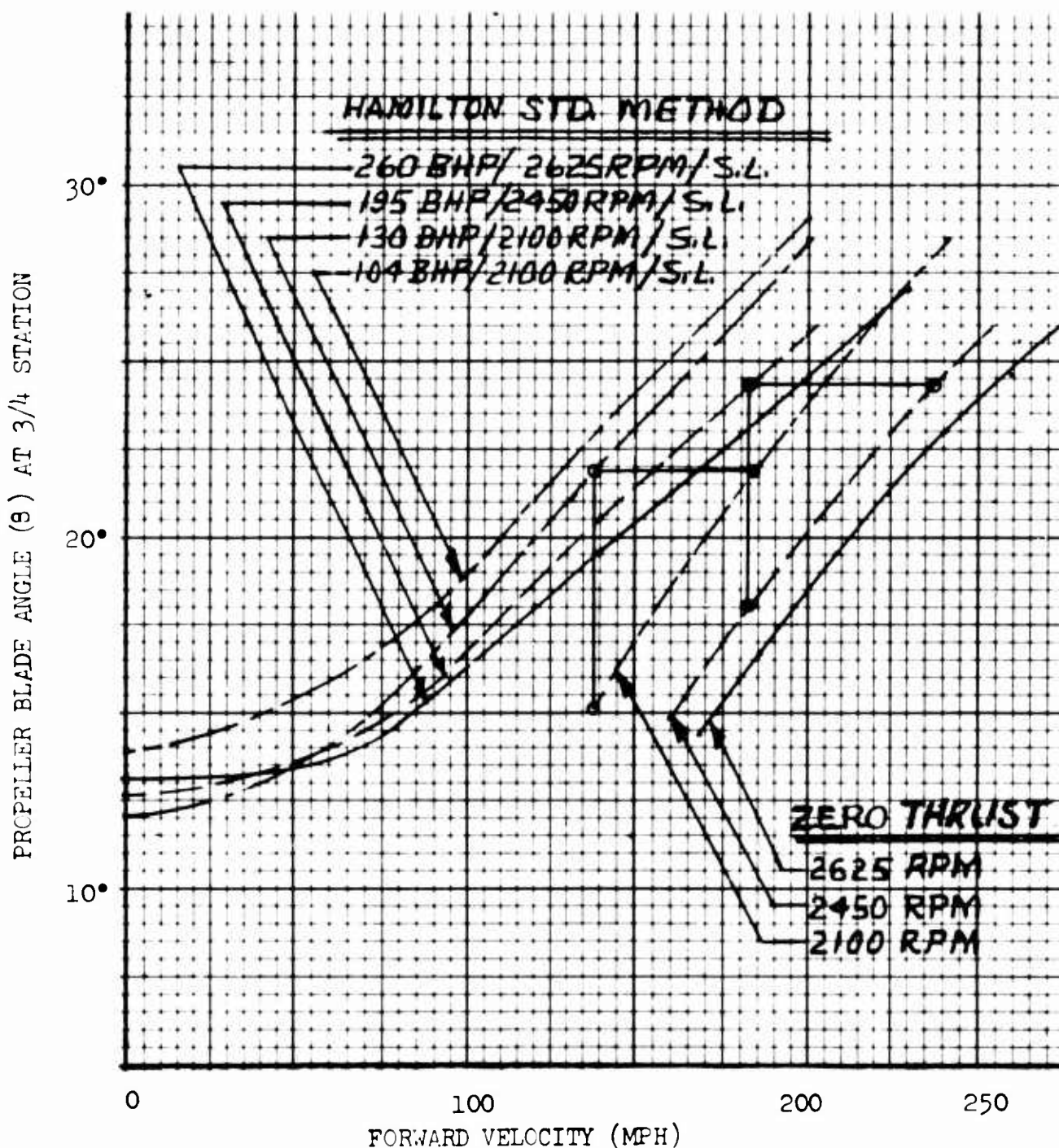


FIGURE 4 - PROPELLER PERFORMANCE FOR AN AIRPLANE WITH A 260 HORSEPOWER ENGINE AND 82 INCH DIAMETER 2 BLADE ADJUSTABLE PITCH PROPELLER

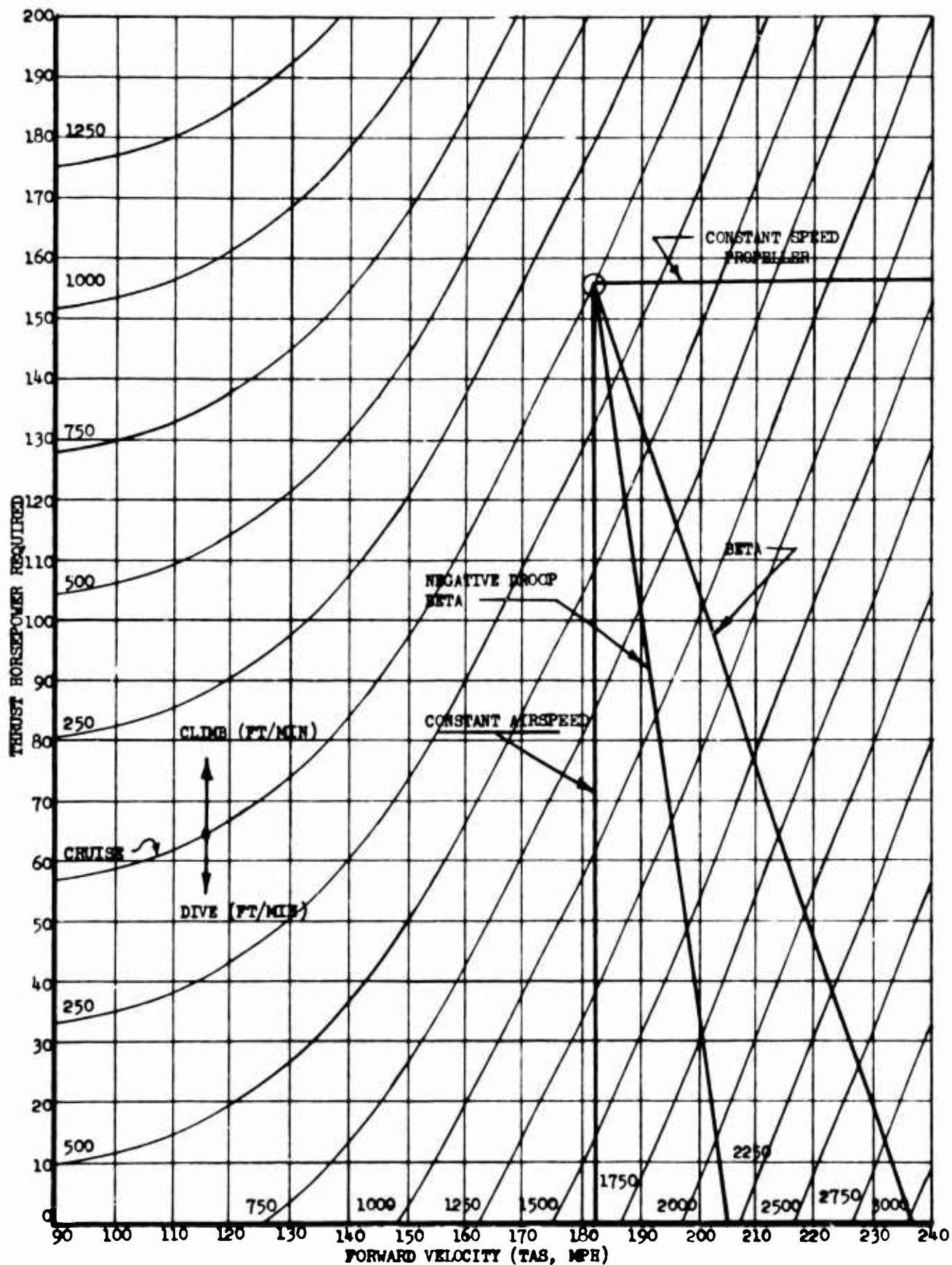


FIGURE 5 - THRUST HORSEPOWER VS AIR SPEED  
AT CONSTANT RATES OF CLIMB OR  
DESCENT FOR AN AIRPLANE WITH  
3125 POUND GROSS WEIGHT

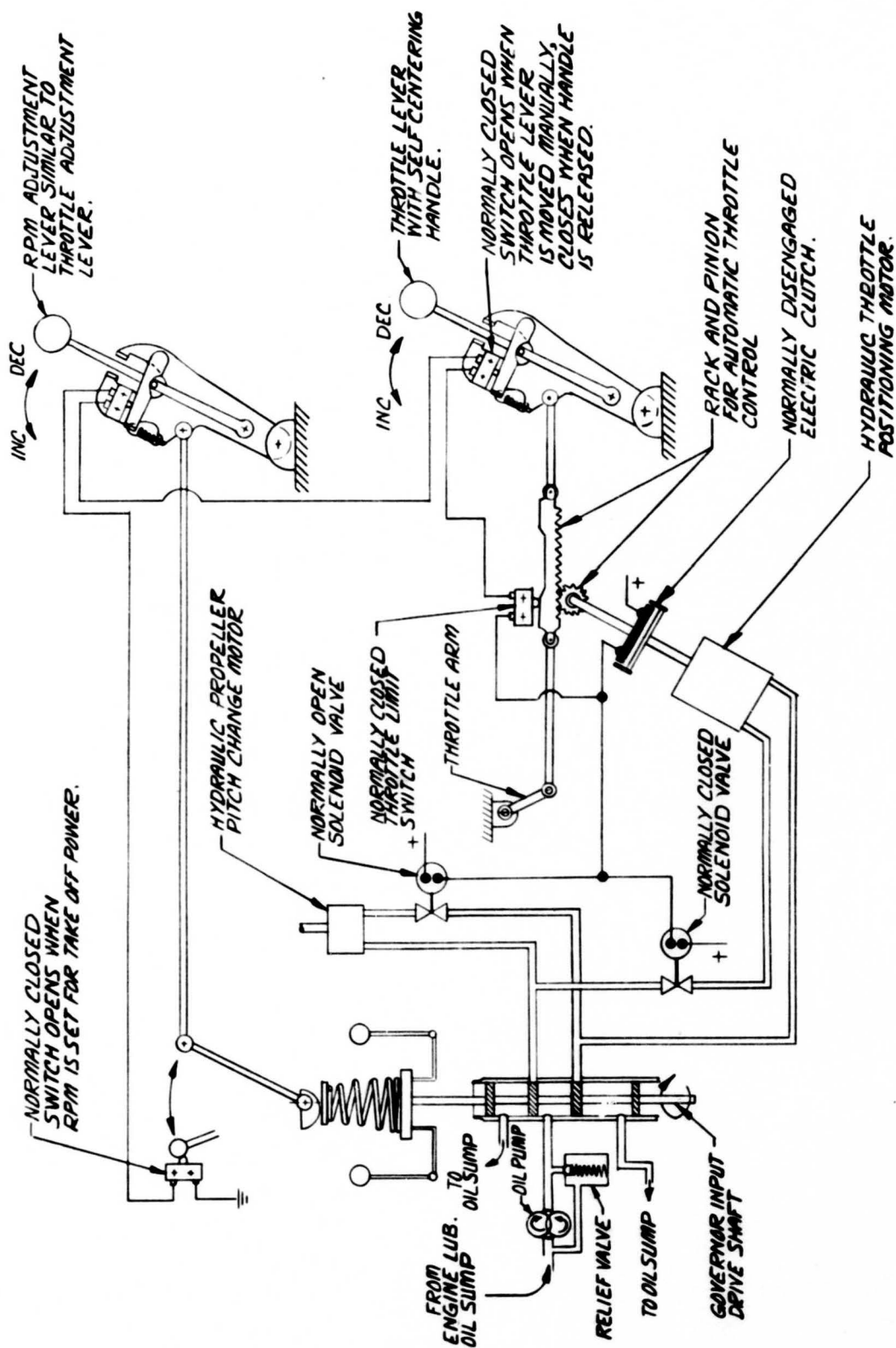


FIGURE 6 - THE LOCKPITCH PROPELLER CONTROL SYSTEM

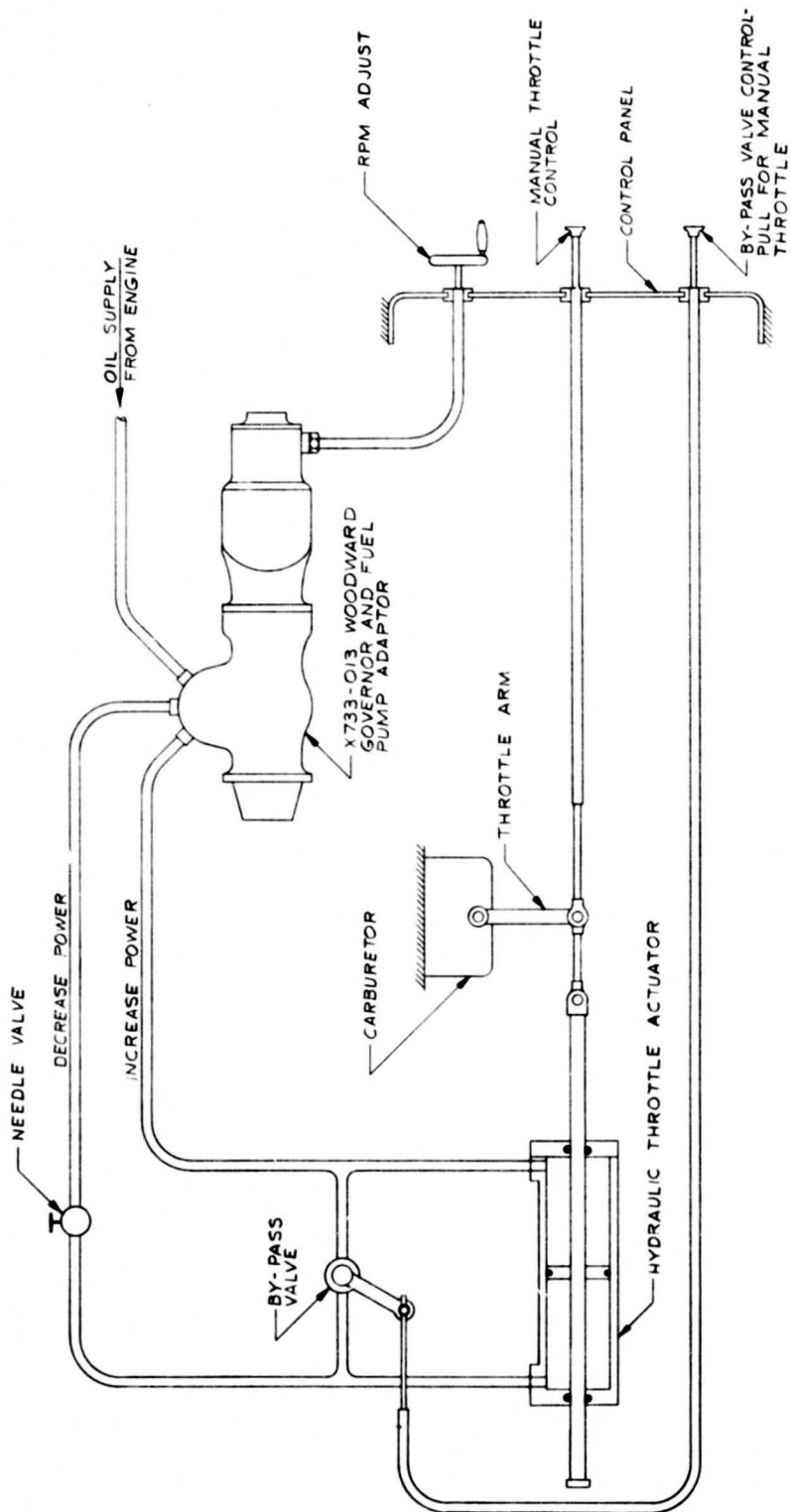


FIGURE 7 - SCHEMATIC DIAGRAM, MANUAL-BETA  
AUTOMATIC-THRUST CONTROL SYSTEM  
USED IN THE FLIGHT TEST AIRPLANE



FIGURE 8 - PHOTOGRAPH OF THE AIRPLANE USED FOR FLIGHT  
TEST OF THE MANUAL-BETA, AUTOMATIC-THRUST SYSTEM

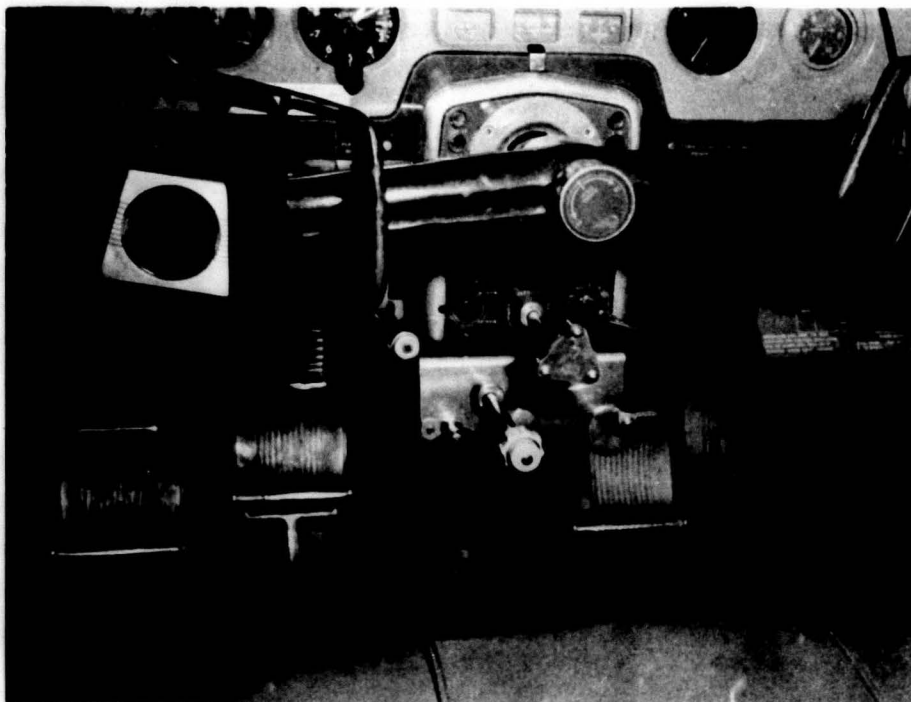


FIGURE 9 - PILOTS CONTROLS FOR THE MANUAL-BETA,  
AUTOMATIC-THRUST CONTROL SYSTEM FLIGHT TESTS

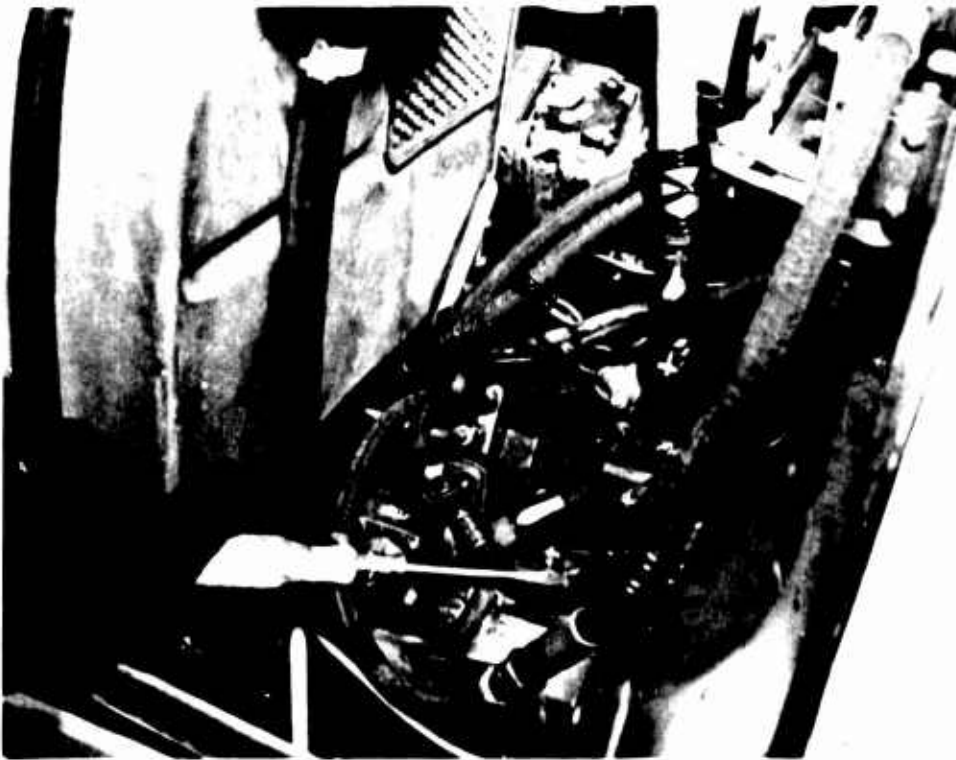


FIGURE 10 - GOVERNOR INSTALLATION FOR THE MANUAL-BETA,  
AUTOMATIC-THRUST SYSTEM FLIGHT TEST

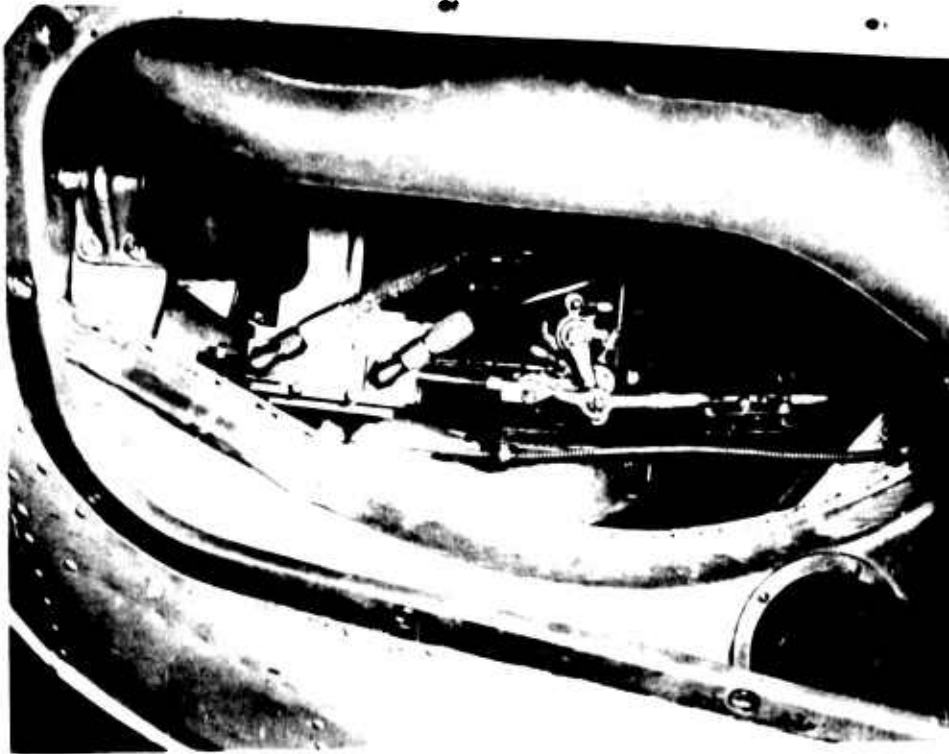


FIGURE 11 - THROTTLE ACTUATOR INSTALLATION FOR THE  
MANU'I-BETA, AUTOMATIC-THRUST SYSTEM FLIGHT TEST

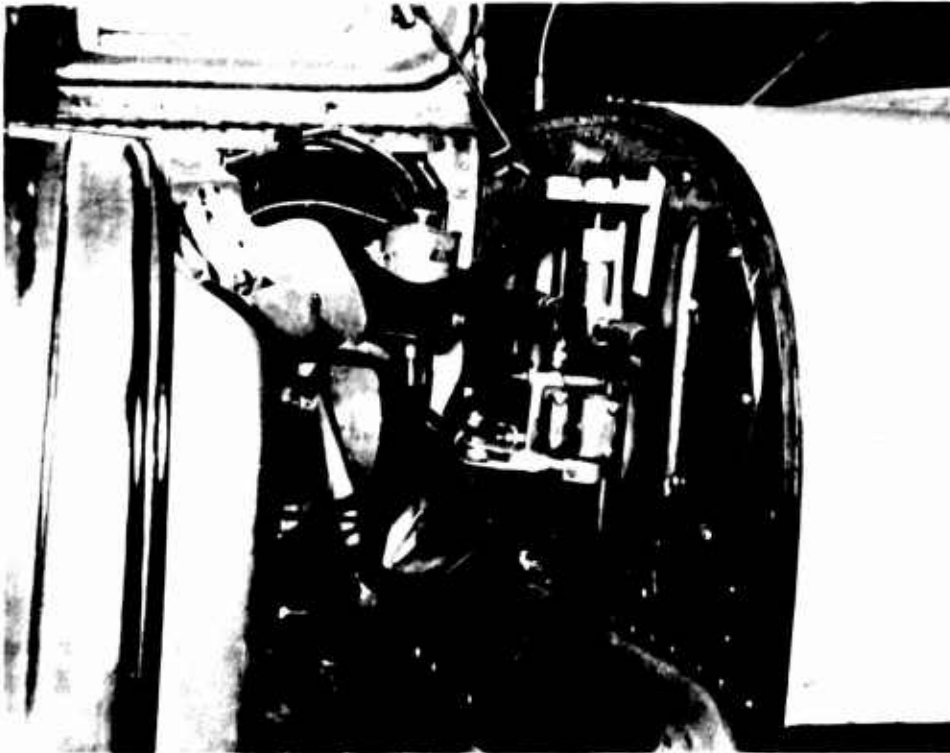


FIGURE 12 - NEEDLE VALVE AND BY-PASS VALVE INSTALLATION  
FOR THE MANUAL-BETA, AUTOMATIC-THRUST SYSTEM  
FLIGHT TEST

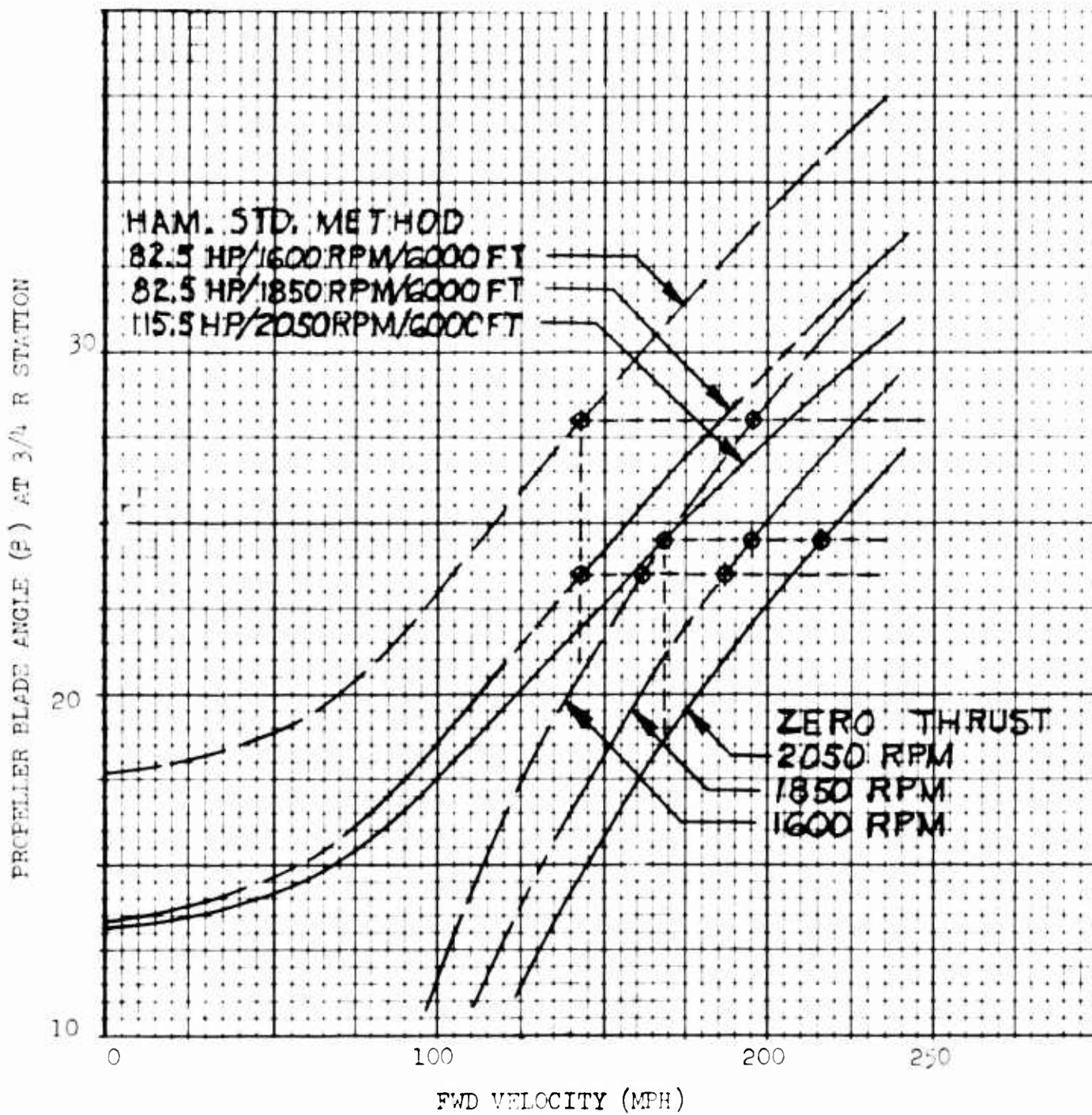


FIGURE 13 - PROPELLER PERFORMANCE FOR THE FLIGHT TEST AIRPLANE

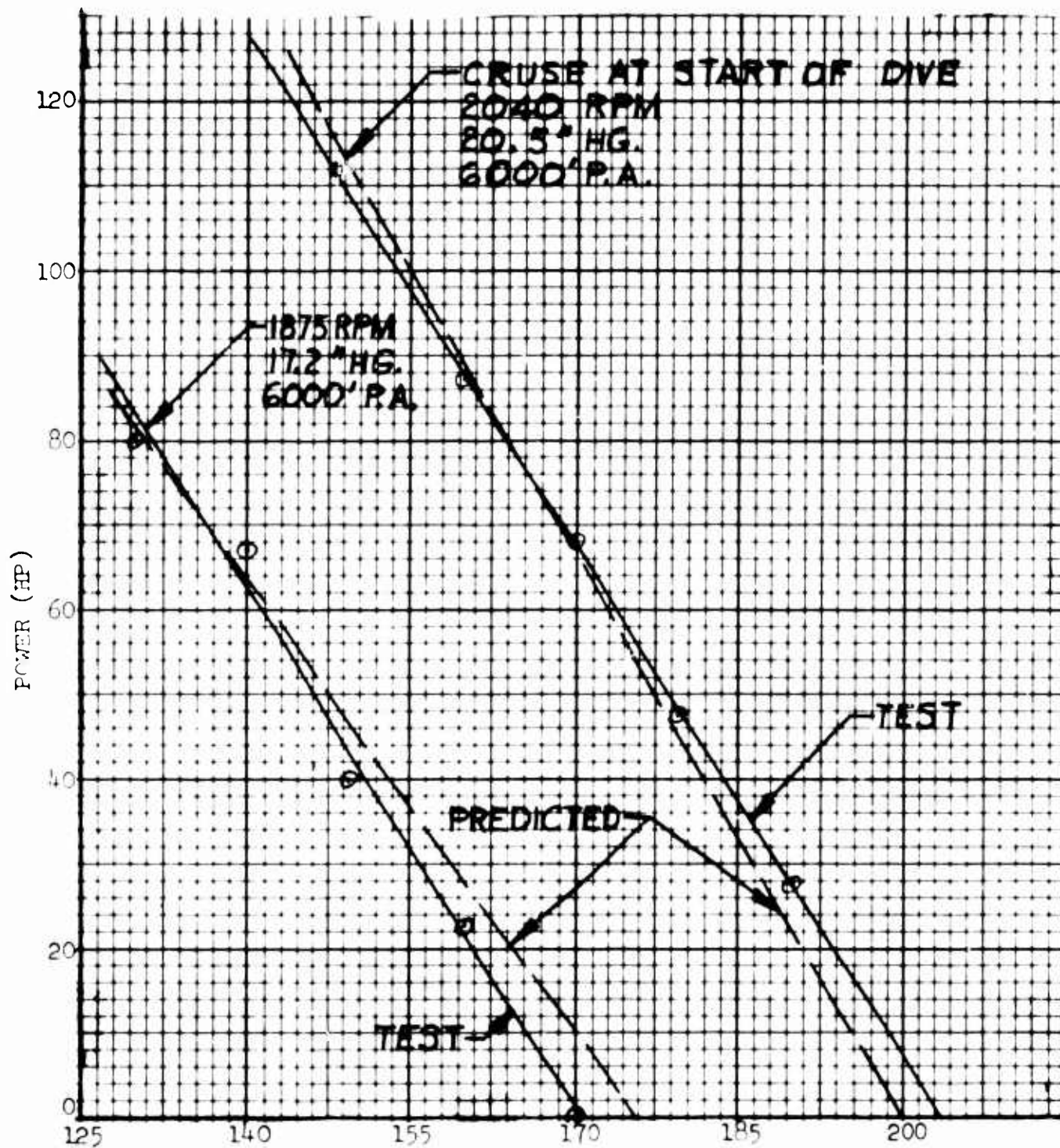


FIGURE 14 - INDICATED AIR SPEED VS POWER REQUIRED IN A DIVE WITH THE MANUAL-BETA, AUTOMATIC-THRUST SYSTEM

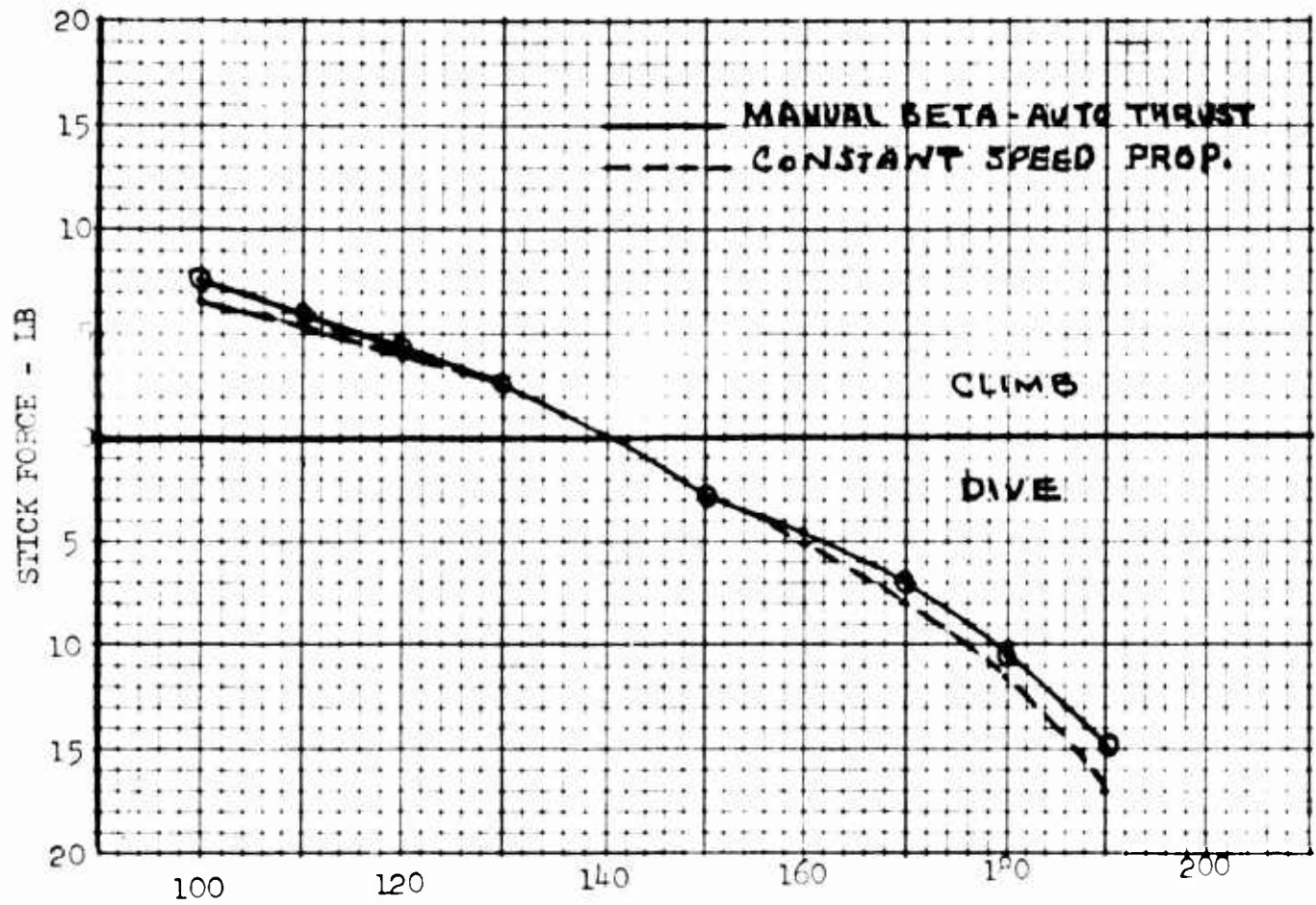


FIGURE 15 - STICK FORCE VS AIR SPEED FOR THE MANUAL-BETA, AUTOMATIC-THRUST SYSTEM AND THE CONSTANT SPEED PROPELLER SYSTEM FLIGHT TEST

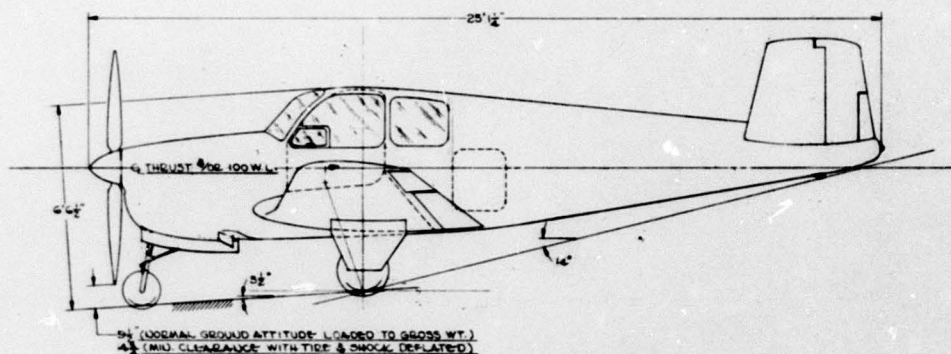
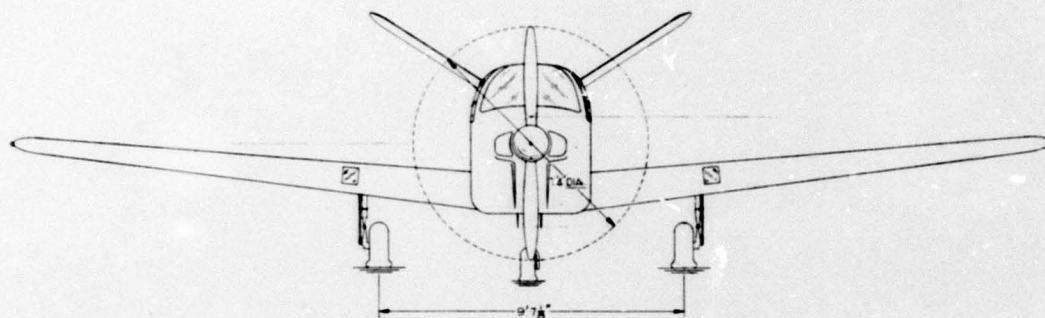
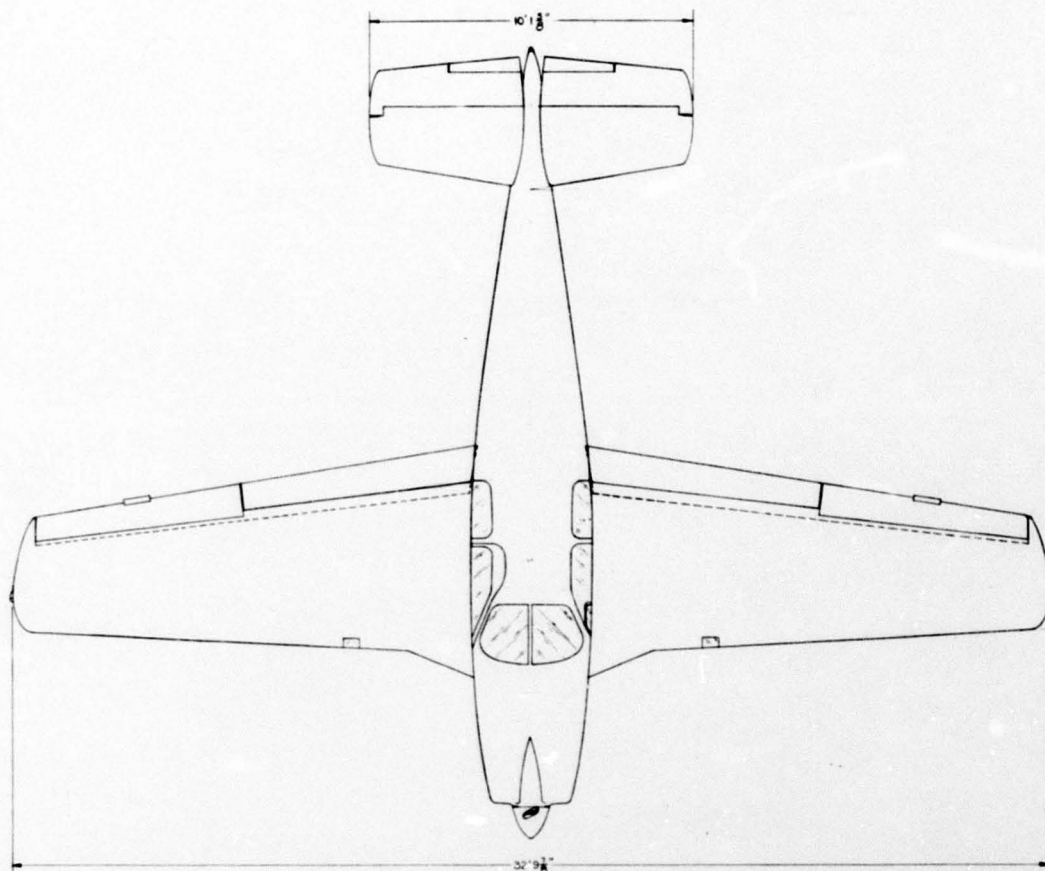


FIGURE 16 - THE FLIGHT TEST AIRPLANE



TABLE 2

DIVE RECOVERY TEST (PHUGOID) WITH THE  
MANUAL-BETA, AUTOMATIC-THRUST SYSTEM,  
WITH FORWARD CENTER OF GRAVITY LOADING

TIME SEC	ALT FT	IAS MPH	RPM	MP IN. Hg
0	8630	100	1750	21
15	8060	161	2050	15
32	8440	119	1950	21
49	8200	146	2050	18
1:05	8420	127	2050	21
1:23	8310	141	2050	19
1:37	8440	132	2050	21
1:55	8440	137	2050	20

AIRPLANE TRIMMED TO 140 MPH IAS AT 8000 FT ALT  
2050 RPM 19 IN. Hg MP - FLIGHT TEST AIRPLANE

TABLE 3

DIVE RECOVERY TEST (PHUGOID) WITH THE  
FIXED THROTTLE, CONSTANT - SPEED PROPELLER  
SYSTEM AT FORWARD CENTER OF GRAVITY LOADING

TIME SEC	ALT FT	IAS MPH	RPM	MP IN. Hg
0	8460	100	1875	18.7
18	7880	161	2100	19
32	8360	112	2000	18.7
50	7920	154	2010	19
1:05	8290	120	2020	18.7
1:23	8020	148	2050	19
1:38	8270	125	2020	19
1:55	8070	143	2050	19
2:12	8240	128	2030	19
2:32	8100	141	2050	19
2:50	8230	130	2000	19
3:05	8140	139	2050	19

AIRPLANE TRIMMED TO 140 MPH IAS AT 8000 FT ALT  
2050 RPM 19 Hg - FLIGHT TEST AIRPLANE

TABLE 4

DIVE RECOVERY TEST (PHUGOID) WITH THE  
FIXED-PITCH FIXED-THROTTLE SYSTEM AT  
FORWARD CENTER OF GRAVITY LOADING

TIME SEC	ALT FT	IAS MPH	RPM	MP IN. Hg
0	8500	100	1700	19.2
17	7800	168	2050	18.7
30	8400	110	1900	19
50	7900	159	2150	19
1:05	8300	115	1900	19
1:25	8000	153	2100	19
1:40	8300	121	1920	19
1:55	8040	148	2100	19
2:07	8260	125	1920	19
2:27	8060	146	2050	19
2:40	8240	127	2000	19
2:56	8100	143	2050	19
3:12	8240	129	1975	19
3:30	8110	140	2050	19

AIRPLANE TRIMMED FOR 140 MPH IAS 8000 FT  
ALT 2050 RPM 19 IN. Hg - FLIGHT TEST AIRPLANE

TABLE 5

DIVE RECOVERY (PHUGOID) WITH THE  
MANUAL-BETA, AUTOMATIC-THRUST CONTROL SYSTEM  
AT AFT CENTER OF GRAVITY LOADING

ALT FT	IAS MPH	RPM	MP IN. Hg
8360	100	1700	21.5
7600	179	2200	21.5
-----	106	-----	-----
7660	174	2200	21.5
8270	114	1800	21.5
7720	169	2050	21.5
8250	116	1750	20.5
7750	165	2100	21.5
8220	122	1750	21.5

AIRPLANE TRIMMED TO 150 MPH IAS 8000 FT ALT  
(COLD TEMP CONDITION CAUSED SLOW  
GOVERNOR CONTROL OF THE THROTTLE)

TABLE 6

DIVE RECOVERY (PHUGOID) WITH CONSTANT  
SPEED PROPELLER AND AFT CENTER OF  
GRAVITY AIRPLANE LOADING

ALT FT	IAS MPH	RPM	MP IN. Hg
7700	150	2050	22.0
8400	100	1900	21.0
7600	176	2450	21.5
8370	111	2050	20.5
7780	171	2050	20.5
8340	117	2000	20.5
7860	167	2200	21.0
8310	123	1900	20.5
7910	163	2200	21.0

**TABLE 7**

**DIVE RECOVERY (PHUGOID) WITH  
FIXED PITCH PROPELLER - FIXED THROTTLE  
SYSTEM AND AFT CENTER OF GRAVITY LOADING**

<b>ALT FT</b>	<b>IAS MPH</b>	<b>RPM</b>	<b>MP IN. Hg</b>
7500	150	2050	22.0
8200	100	1550	21.5
7310	178	2050	22
8050	108	1550	21.5
7310	175	2000	21.5
7930	115	1600	21.5
7315	170	2000	21.5
7800	122	1650	21.5
7330	116	1700	21.5
7710	128	1700	21.5
7350	160	1900	21.5
7650	130	1700	21.5

TABLE 8

DIVE SPEED TESTS, COMPARISON OF MANUAL-  
 BETA, AUTOMATIC-THRUST SYSTEM WITH CONSTANT  
 SPEED PROPELLER SYSTEM WHEN TRIMMED TO 120 MPH  
 AND DIVED TO 160 MPH, AND TRIMMED TO 150 MPH AND DIVED AT 180 MPH

SYSTEM IN TEST	IAS MPH	ALT FT	TIME SEC	DIVE ANGLE DEGREES	AVE RATE OF DESCENT FT/MIN
Manual Beta Automatic Thrust System	120 160 160 160 160	8220 7520 7200 7040 6850	0 19 29 35 40	0 } 3.24	1915
Constant Speed Propeller System	120 160 160 160 160	8270 7710 7620 7530 7470	0 24 31 37 42	0 } 7.85	800
Manual Beta Automatic Thrust System	150 180 180 180 180	8250 7705 7610 7510 7415	0 23 28 32 36	0 } 2.94	1340
Constant Speed Propeller System	150 180 180 180 180	8090 7540 7465 7400 7324	0 31 37 42 47	0 } 4.90	810